



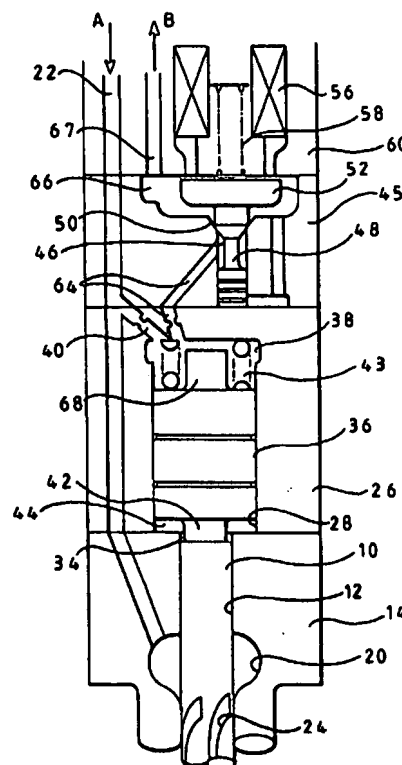
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(54) Title: FUEL INJECTOR

## (57) Abstract

A fuel injector comprising a valve needle (10) engagable with a seating to control fuel flow through an outlet, the valve needle (10) slidable in a first bore and including at least one thrust surface oriented such that the application of fuel under pressure thereto applies a force to the valve needle (10) urging the valve needle (10) away from the seating; a valve member (48) for controlling fuel pressure within a control chamber (38) for controlling the position of the valve needle (10) relative to the seating; and a piston member (36) slidable within a second bore (28), and defining, with the second bore (28), the control chamber (38); wherein the piston member (36) is exposed at one end portion thereof to fuel pressure within the control chamber (38), is cooperable with the valve needle (10) to transmit the force applied by the fuel pressure to the valve needle (10), and has an effective area exposable to fuel pressure so as to urge the valve needle (10) towards the seating greater than the effective area of the thrust surface or surfaces, respective opposite end portions of the piston member (36) and the valve needle (10) defining, with the first and/or second bore an intermediate chamber (44), the injector being arranged so as to permit the pressure in the intermediate chamber to be varied during an injection cycle.



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## **FUEL INJECTOR**

**This invention relates to a fuel injector for use in delivery of fuel under pressure to a cylinder of an associated compression ignition internal combustion engine. In particular, the invention relates to a fuel injector of the type suitable for use in a fuel supply system of the common rail type, the injector being actuable to permit fuel to be delivered to the cylinder of the associated engine from the common rail, the common rail being charged with fuel under pressure by an appropriate high pressure fuel pump. A plurality of similar injectors is arranged to receive fuel from the common rail.**

**It is known to control the operation of such a fuel injector by using a valve to control the fuel pressure within a control chamber, the fuel pressure within the control chamber acting upon a surface associated with the needle of the injector to apply a force to the needle urging the needle towards its seating. In order to ensure that injection terminates quickly upon closing the valve, it is known to use a flow restrictor to limit the fuel pressure acting on the needle and urging the needle away from its seating.**

**According to the invention there is provided a fuel injector comprising a valve needle slidable in a first bore and engagable with a seating to control fuel flow through an outlet, the valve needle including at least one thrust surface oriented such that the application of fuel under pressure thereto applies a force to the valve needle urging the valve needle away from the seating; a valve member for controlling fuel pressure within a control chamber for controlling the position of the valve needle relative to the seating; and a piston member slidable within a second bore, and defining, with the second bore, the control**

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chamber; wherein the piston member is exposed at one end portion thereof to fuel pressure within the control chamber, is cooperable with the valve needle to transmit the force applied by the fuel pressure to the valve needle, and has an effective area exposable to fuel pressure so as to urge the valve needle towards the seating greater than the effective area of the thrust surface or surfaces, respective opposite end portions of the piston member and the valve needle defining, with the first and/or second bore, an intermediate chamber, the arrangement being such that the pressure in the intermediate chamber is varied during an injection cycle.

This arrangement is advantageous in that it facilitates a reduction in the pressure differential between the control chamber and the or each thrust surface on the one hand and the intermediate chamber on the other hand, and tends to minimise leakage to low pressure.

In particular, this facilitates a more energy efficient fuel injector than one in which the intermediate chamber is permanently connected to a low-pressure region.

The arrangement is also advantageous in that the use of flow restrictors restricting the rate of fuel flow towards the seating can be avoided, the difference in area producing the biasing force necessary to cause rapid termination of injection. By avoiding the use of flow restrictors, the loss of pressure during injection is reduced.

The intermediate chamber may conveniently be a closed chamber. In this case, there is negligible leakage to low pressure, and pumping losses are consequently minimised. Some heat energy loss may occur due to flow within

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the injector. For example, with the valve needle open flow may occur from high-pressure regions, for example from the control chamber by way of a controlled clearance between the piston member and the bore, into the intermediate chamber. This internal flow tends to cause a gradual increase in pressure in the intermediate chamber and a consequential gradual reduction in the internal flow. The volume of internal flow which needs to be recovered into the control chamber at the end of an injection event is therefore self-limiting.

As the volume of the intermediate chamber is reduced during movement of the piston member and the valve needle towards the seating, increasing the pressure in the intermediate chamber still further, subsequent damping of the piston movement may occur, which may result in loss of contact between the piston and valve needle. It has been found that this can be tolerated in certain injection regimes, particularly since the momentum of the valve needle together with the over-pressure in the intermediate chamber acting on the valve needle drives the needle into its closed position in engagement with the seating. Subsequently, leakage of fluid back out of the intermediate chamber, for example to the control chamber, should allow the piston member to return to its original position in engagement with the valve needle. However, the start of the next injection cycle may occur before the piston has time to return fully.

Accordingly, the fuel injector may further comprise resilient biasing means biasing the piston member towards the valve needle. This assists the return of the piston member into engagement with the valve needle in the required time. The biasing means further assists in sealingly retaining the valve needle against its seat for preventing the siphoning of fuel into a cylinder of an engine when the engine is not running.

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Furthermore the injector may comprise vent means for venting the intermediate chamber to low pressure, for example into the control chamber. This facilitates the release of over-pressure from the intermediate chamber as required, for keeping the piston member in engagement with the valve needle.

The vent means may be arranged to permit fluid communication between the intermediate chamber and the control chamber during or following movement of the valve needle and the piston member towards the seating and to substantially prevent fluid communication between the control chamber and the intermediate chamber during movement of the valve needle with the piston member away from the seating.

The vent means may include valve means arranged to allow fluid communication between the intermediate chamber and the control chamber when a predetermined over-pressure is reached in the intermediate chamber.

The vent means may comprise a vent passage through the piston member. The valve means may comprise a valve member disposed in the control chamber and resiliently biased towards the piston member for closing said vent passage. The valve member may be resiliently biased towards the piston member by said resilient biasing means.

Alternatively, the vent means may comprise a vent passage in a piston housing. The injector may further comprise valve means disposed in the control chamber.

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In a further alternative embodiment, the vent means may comprise a vent passage through the piston member arranged to allow fluid communication between the intermediate chamber and the control chamber when the piston member and the valve needle separate.

The vent passage may open into an end face of the piston member which mates with an end face of the valve needle in a fluid-tight manner when the piston member and valve needle are driven towards one another.

The intermediate chamber may communicate with the control chamber along a restricted flow path so as to cause a pressure differential between the chambers. In one such embodiment, the restricted flow path is through the piston member.

The intermediate chamber may also be in fluid communication with a spill passage for spilling fuel to a low pressure source under control of the valve member. This may facilitate achieving a relatively short time period between the end of a pilot injection and the start of the following primary injection. In another such alternative embodiment, the restricted flow path is through the piston housing.

The spill passage may be provided with valve means which serve to prevent the over-pressurisation of fuel within the intermediate chamber. Additionally, the valve means may be arranged to ensure low pressure is trapped within the intermediate chamber at the onset of closure of the valve needle. This aids

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relatively rapid closure of the valve needle.

The valve means may be arranged within the spill passage. Preferably, the restricted flow path does not communicate directly with the spill passage such that operation of the valve means is substantially unaffected, in use, by the passage of fuel through the restricted flow path.

In any of the embodiments of the invention, the valve needle may have a greater effective area exposable to fuel pressure within the intermediate chamber than the effective area of the thrust surface or surfaces. This ensures that high pressure in the intermediate chamber tends to urge the valve needle towards the seating.

In order that the invention may be well understood, various embodiments thereof, which are given by way of example only, will now be described with reference to the accompanying drawings, in which:

Figure 1 is a sectional view of part of an injector in accordance with a first embodiment;

Figure 2 is a sectional view of part of an injector in accordance with a second embodiment;

Figure 3 is a sectional view of part of an injector in accordance with a third embodiment;

Figure 4 is a sectional view of part of an injector in accordance with a fourth embodiment;

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Figure 5 is a sectional view of part of an injector in accordance with a fifth embodiment;

Figure 6 is a sectional view of part of an injector in accordance with a sixth embodiment;

Figure 7 is a sectional view of a part of an injector in accordance with a seventh embodiment of the invention;

Figure 8 is a sectional view of a part of an injector in accordance with an eighth embodiment of the invention; and

Figure 9 is a sectional view of a part of an injector in accordance with a ninth embodiment of the invention; and

The injector illustrated in Figure 1 comprises a valve needle 10, which is slidable within a blind bore 12 formed in a nozzle body 14. The valve needle 10 includes, at its lower end, a frusto-conical surface (not shown) which is arranged to engage a frusto-conical seating (not shown) formed adjacent the blind end of the bore 12, engagement of the valve needle 10 with the seating controlling the supply of fuel from the bore 12 to one or more outlet openings (not shown) which communicate with the bore 12 downstream of the seating.

The bore 12 is shaped to define an annular gallery 20 which communicates with an inlet passage 22 whereby fuel is supplied in the direction of Arrow A from a source of fuel under high pressure, for example a common rail charged with fuel to a high pressure by a suitable high pressure fuel pump. The needle

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10 is of stepped form and defines a thrust surface (not shown) which is angled such that the application of fuel under high pressure thereto applies a force to the valve needle urging the valve needle 10 in an upward direction away from the seating, in the orientation illustrated. Similarly, the application of fuel under high pressure to the frusto-conical end region (not shown) of the needle 10 applies a force to the needle 10 urging the needle 10 away from its seating. The needle also has helical recesses 24 extending coaxially therealong for assisting the passage of fuel to the injector outlet. These recesses also provide surfaces, which may assist urging of the valve needle upwards.

The upper end of the nozzle body 14 abuts a piston housing 26 which is shaped to define a blind bore 28 which, preferably, extends coaxially with the bore 12 of the nozzle body 14. Alternatively, the bore 28 could be axially offset with respect to the bore 12 so as to provide sufficient space for the inlet passage 22.

A piston 36 is located in the bore 28 in sliding engagement with the bore 28. The piston 36 and upper end of the bore 28 together define a control chamber 38, which communicates, through a passage 40, provided with a restriction 40a, with the supply passage 22. A closed intermediate chamber 44 is formed between the piston 36 and valve needle 10. The chamber is defined by the lower surface of the piston 36, the upper surface 34 of the valve needle 10 and the portions of bores 12 and 28 which lie intermediate these surfaces. A thrust pin 42 of relatively short axial length extends from the lower portion of the piston 36 into engagement with the upper surface 34 of the valve needle 10. A helical compression spring 43 is situated in the control chamber 38 in abutment with the roof of the chamber 38 and an upper surface of the piston 36, so as to resiliently bias the piston 36 with thrust pin 42 towards engagement with the valve needle 10.

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The upper surface of the piston housing 26 abuts the lower surface of a valve housing 45 which is provided with a through bore 46 within which a control valve member 48 is slidable. The control valve member 48 includes an upper end region of enlarged diameter which is engagable with a seating 50 defined around an upper end of the through bore 46. The upper end of the valve member 48 is connected to an armature 52 which is moveable under the influence of a magnetic field generated, in use, by an actuator including windings 56. A spring 58 is arranged to bias the valve member 48 into engagement with the seating 50. The actuator and spring 58 are located within a nozzle holder 60, a cap nut (not shown) being in screw-threaded engagement with the nozzle holder 60 and securing the nozzle body 14, the piston housing 26 and the valve housing 45 to the nozzle holder 60.

The control chamber 38 communicates through passages 64 with an annular chamber defined between a region of the valve member 48 of reduced diameter and the bore 46 within which the valve member 48 is slidable. The part of the passage 64 provided in the housing 26 is provided with a restriction 64a to restrict the rate of fuel flow therethrough, as will be described in further detail herein after. When the valve member 48 engages its seating 50, the valve member 48 is substantially fuel pressure balanced, and the spring 58 is of sufficient strength to cause the valve member 48 to remain in this position. Energization of the actuator results in movement of the valve member 48 away from the seating 50 against the action of the spring 58 resulting in fuel being permitted to flow from the control chamber 38 to a chamber 66 within which the armature 52 is located, the chamber 66 communicating through a passage 67 with a low pressure drain or reservoir to which fuel flows in the direction of

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Arrow B. De-energization of the actuator allows the valve member 48 to return to the position illustrated under the action of the spring 58.

In use, with the actuator de-energized and with the supply passage 22 supplied with fuel under high pressure from an appropriate source, for example a common rail charged with fuel under high pressure by an appropriate pump, it will be appreciated that the thrust surface of the valve needle 10 and the exposed part of the frusto-conical surface of the valve needle 10 are supplied with fuel under pressure, and thus a force is applied to the valve needle 10 urging the needle 10 away from its seating. This force is opposed by the action of the spring 43 and by the action of fuel under pressure within the control chamber 38 upon the exposed end surfaces of the piston 36. The effective area of the piston 36 exposed to the fuel pressure within the control chamber 38 is greater than the effective areas of the thrust surface and the exposed part of the frusto-conical surface of the valve needle. It will be appreciated that the net force applied to the needle 10 is a downward force, urging the valve needle 10 to remain in engagement with its seating. This downward force has components provided by the spring 43 and the force exerted on the top of the needle 10 by the pressurised fuel in the intermediate chamber. In this connection, the effective area at the top of the valve needle 10 that is exposed to pressure is greater than the effective areas of the thrust surface and the frusto-conical surface of the valve needle 10, to assist in holding the valve closed once pressure has built up in the intermediate chamber 44. Therefore, injection does not occur in this condition.

In order to commence injection, the actuator is energized resulting in upward movement of the valve member 48 against the action of the spring 58. Such movement of the valve member 48 permits fuel to escape from the control

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chamber 38 thus reducing the fuel pressure applied to the piston 36. It will be appreciated that the presence of the restricted passage 40, 40a restricts the rate at which fuel flows to the control chamber 38 from the supply passage 22, thus the movement of the valve member 48 away from the seating 50 results in a reduction in the fuel pressure within the control chamber 38. It will further be appreciated that the rate of pressure drop in the control chamber 38, and the final low pressure level in the control chamber 38, can be controlled by appropriate sizing of the restrictions 40a, 64a.

The reduction in fuel pressure applied to the top of the piston 36 gives rise to a pressure difference between the control chamber 38 and the exposed annular area of the valve needle 10 at its lowermost tip region (i.e. the frusto-conical surface which is engageable with the valve needle seating), the pressure difference being sufficient to lift the piston 36 and the valve needle 10 in an upwards direction. Thus, a point will be reached beyond which the valve needle 10 is able to move away from its seating, thus permitting fuel to flow to the outlet openings, and through the openings to the cylinder or combustion space of the associated engine within which the injector is mounted.

The volume of the control chamber 38 is relatively small, and as upward movement of the valve needle 10 occurs, a pin 68 forming the upper end of the piston member 36 may move into engagement with the blind end of the bore 28 thus acting to limit upward movement of the piston member 36 and the valve needle 10.

It will be appreciated that, during injection, a small quantity of fuel flows from the supply passage 22 through the restricted passage 40, 40a to the control chamber 38 and from the control chamber 38 through the restricted passage 64,

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64a, past the control valve seating 50 to the low pressure drain. The dimensions of the restricted passages 40, 40a, 64, 64a are chosen to ensure that the quantity of fuel under pressure, which is able to escape in this manner, is minimised.

In order to terminate injection, the actuator is de-energized and the valve member 48 returns into engagement with the seating 50 under the action of the spring 58. Such movement of the valve member 48 prevents further fuel from escaping from the control chamber 38 to the low pressure drain, and the continued supply of fuel through the restricted passage 40 to the control chamber 38 results in the fuel pressure within the control chamber 38 increasing. Clearly, therefore, the fuel pressure applied to the piston member 36 and hence the force transmitted through the thrust pin 42 to the valve needle 10 is increased, and a point will be reached beyond which the action of the fuel pressure within the control chamber 38 in combination with the action of the spring 43 is sufficient to cause the valve needle 10 to move towards engagement with its seating, to terminate the supply of fuel to the outlet openings and terminate injection. As the effective area of the piston 36 is greater than that of the thrust surfaces of the needle, such movement of the piston 36 and valve needle 10 occurs rapidly.

It will be appreciated that as the thrust pin 42 is of relatively short axial length, even though the thrust pin 42 is of small diameter, for example 2mm, flexing or compression of the thrust pin 42 to a significant extent does not occur. As a result, when the fuel pressure within the control chamber 38 reduces when injection is to commence, the initial movement of the piston 36 does not simply result in extension of the thrust pin 42 but rather the valve needle 10 commences movement immediately. Jerky movement of the injector needle is

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therefore reduced or avoided, and injection is more controlled. Although in the description hereinbefore the thrust pin 42 is described as being an extension of the piston, it will be appreciated that the thrust pin may form a separate component or an extension of the valve needle, if desired.

It should be noted that, with the valve needle 10 in the closed position, flow of high-pressure fuel around the piston 36 and needle 10 into the intermediate chamber 44 may increase the pressure in the intermediate chamber 44. In such a case there is still a net force, resulting from the biasing force of the spring 43 and the fuel pressure within the control chamber 38, holding the valve needle 10 against the seating. During opening movement of the valve needle 10, the volume of the intermediate chamber 44 increases and the pressure therein reduces further. This ensures the area advantage provided by the effective area of the piston 36 being greater than the effective area of the valve needle thrust surfaces, is maintained.

Any high pressure fuel leakage into the intermediate chamber 44 during lifting of the piston 36 or with the piston 36 in the uppermost position will contribute to causing an over-pressure in the intermediate chamber 44 once the piston 36 moves downwards to close the valve needle 10 against the seating. However, this does not prevent rapid valve closure because the initially relatively low pressure in the intermediate chamber 44 on commencement of the downward stroke of the piston 36 enables the piston to impart sufficient momentum to the valve needle 10 to bring the valve needle 10 against the seating. However, the downward movement of the piston may be damped as the fuel, including leakage fuel, in the intermediate chamber 44 is compressed. Separation of the piston 36 and valve needle 10 may then occur. If the time between injections is

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sufficient, the spring 43 will return the piston 36 into engagement with the valve needle 10.

Whilst damping of the downward piston movement and separation of the piston 36 and valve needle 10 may be tolerated in some injection regimes, various modifications of the aforescribed embodiment will now be described which mitigate against such problems by venting the intermediate chamber into the control chamber. In the following description of these modifications, a detailed description of features that are identical to those described with respect to Figure 1 is omitted.

Figure 2 shows a modified injector which is substantially identical to the injector of Figure 1 except for a vent passage 72 through the piston member 36A and a valve member 74 disposed in the control chamber 38A. The valve member 74 is resiliently biased against a seat on the top of piston 36A by a spring 43A, whereby one end of the vent passage 72 is closed off. The vent passage 72 provides fluid communication between the intermediate chamber 44A and the control chamber 38A when over-pressure in the intermediate chamber 44A lifts the valve member 74 from its seat on the upper surface of the piston 36A, for example, when the piston is driven downwards and reduces the volume of the intermediate chamber 44A into which high pressure fuel has leaked. This opening of the vent passage 72 to relieve the pressure in the intermediate chamber 44A alleviates the aforementioned problem of piston damping. Clearly, the plate-valve valve member shown could be substituted for another type of one-way valve, for example a one-way valve having a valve spring in addition to the piston-biasing spring or including a valve member of an alternative form, such as a ball valve.

Figure 3 shows another modified injector which is substantially identical to the injector of Figure 1 except for a vent passage 82 through the piston housing 26A and valve means, shown as a ball valve 84, 85 closing off an end of the vent passage 82. The vent passage 82 provides fluid communication between the intermediate chamber 44B and the control chamber 38B so as to by-pass the piston 36B when over-pressure in the intermediate chamber 44 lifts the ball 84 of the ball valve against its spring 85.

Figure 4 shows a still further modified injector which is substantially identical to the injector of Figure 1 except for a vent passage 92 through the piston 36C, the lower end of the vent passage opening into a lower face of the piston 36C which mates with the end face 34C of the valve needle 10C in a fluid-tight manner so as to close the vent passage 92 when the piston 36C and valve needle 10C are driven towards one another. If over-pressure occurs in the intermediate chamber 44C such that the piston 36C and valve needle 10C separate from one another as the piston 36C and valve needle 10C are being driven downwards, the lower end of the vent passage 92 opens to the intermediate chamber 44C, relieving the pressure in the intermediate chamber 44C into the control chamber 38C. When the pressure in the intermediate chamber has dropped sufficiently, the piston 36C is driven by the spring 43C back towards engagement with the valve needle 10C so as to reseat the lower end of the vent passage 92.

Figure 5 shows a still further modified injector that is similar to the injector of Figure 1 except that the control chamber 38D communicates with the intermediate chamber 44D through a passageway 102 in the piston 36D. Also, no lower thrust pin is provided on the piston 36D, and the valve needle 10 is provided at its upper end with a reduced diameter portion 10D, shown in

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abutment with the piston's lower end face. A flow restrictor in the form of a reduced diameter bore portion 103 is provided in the passageway 102. An unrestricted spill passageway 104 is provided in the piston housing 26D for spilling fuel from the intermediate chamber 44D to low pressure via chamber 66 under control of the valve member 48. In the embodiment of Figure 5, all spill flow must first pass through the passageway in the piston 36D and is thus subject to the flow restrictor 103.

The injector in Figure 5 is shown in the closed condition between injections, with the valve member 48 in the closed position. When valve member 48 is opened, the pressure in the intermediate chamber 44D is quickly spilt. The pressure within the control chamber 38D is reduced as fuel flows through the passage 102 and the restricted passage 103, the valve needle 10 and the piston 36D consequently move quickly upwards under the force exerted on thrust surface 105 and on the frusto-conical surface on the valve needle tip by the high pressure fluid from inlet passage 22, overcoming the reduced force due to reduced fuel pressure within the control chamber 38 and the force of the spring 43D, thereby opening the injector. It will be appreciated that, as the intermediate chamber 44D is essentially evacuated, the force applied to the top of the piston 36D and the force applied to the frusto-conical surface of the valve needle tip, will serve to hold the valve needle 10 and the piston 36D together.

When the valve member 48 is closed fluid continues to flow through the passageway 102, maintaining a pressure differential across the flow restrictor 103. This drives the piston 36D downwardly, thereby driving downwardly the valve needle 10, which is in engagement with the piston 36D, against its seating. The pressure differential across the restrictor 103 gradually reduces

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until the pressures in the control chamber 38D and intermediate chamber 44D have equalised. It should be apparent that the intermediate chamber pressure drops below the inlet passage pressure for a short period only, thereby minimising heat losses within the injector.

Figure 6 shows a still further modified injector that is similar to the injector of Figure 1 except that the intermediate chamber 44E communicates through a passageway 106 both with a restricted passage 107 into the control chamber 38E and a spill passage 108 for spilling fluid to a low pressure sink via chamber 66 under control of the valve member 48. Also, a coil spring 109 is disposed in the intermediate chamber 44E about a reduced diameter thrust pin portion 42E of the piston 36E. The spring 109 engages mutually opposite annular surfaces 111,110 of the piston 36E and the needle 10 respectively so as to bias the needle 10 away from the piston 36E and ensure that there is always a closing force acting on the needle 10.

The valve needle 10 may be provided at its upper end with a reduced diameter portion 10E, similar to the portion 10D shown in Fig 5.

Figure 6 shows the injector in normal operation with the valve member 48 closed and the piston 36E in contact with the valve needle 10. Whilst, when pressure in the control chamber 38E and the intermediate chamber 44E has equalised, the spring 109 tends to drive the piston 36E upwards, away from the valve needle 10, in normal operation there is not enough time for this to occur between injections. In the condition shown, when the valve member 48 opens and reduces pressure in the intermediate chamber 44E the upward thrust on the valve needle 10 via thrust surface 105 and the frusto-conical surface on the valve needle tip, gradually drives the valve needle 10 with the piston 36E

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upwards and into the open position, overcoming the force due to reduced fuel pressure in the control chamber 38.

When the valve member 48 is closed, the pressure differential between the control chamber 38E and the intermediate chamber 44E across the restriction 107 results in a downward force on the piston 36E which drives the valve needle 10 downwardly to close the injector. If a long enough period elapses before the valve member 48 opens again the pressure differential is eroded by flow through the restriction 107 to the intermediate chamber 44E, and the spring 109 may drive the piston 36E upwardly as already described.

In this embodiment, losses are reduced in that the intermediate chamber pressure is maintained above the pressure of the low pressure sink for most, or at least some, of the injection cycle.

Referring to Figure 7, there is shown a further alternative embodiment of the invention in which the control chamber 38F communicates with the annular chamber defined between the reduced diameter region of the valve member 48 and the bore 46 by means of a restricted passage 65. The fuel injector also includes a spill passage 81 which provides a return path for fuel from the intermediate chamber 44F to the passage 65 and, thus, past the valve seating 50 whilst the valve member 48 is open. The passage 81 is provided in the piston housing 26 for the piston member 36F and valve means, in the form of a one-way ball valve 83, are provided towards the upper end of the passage 81. The ball valve 83 is engageable with a seating 86 so as to close communication between the passage 81 and the passage 65. If the pressure in the intermediate chamber 44F exceeds the pressure within the passage 65, the ball valve 83 in the passage 81 is lifted from its seating 86, thereby permitting fuel to flow from

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the intermediate chamber 44F into the passage 65. If the pressure in the intermediate chamber 44F does not exceed that in the passage 65, the one way ball valve 83 remains in its seating 86 and prevents any flow of fuel from the passage 65, in communication with the control chamber 38F, into the intermediate chamber 44F. Operation of the ball valve 83 will be described in further detail herein after.

The passage 65 includes a flow restriction 65a, and as a result when the control valve is open the pressure within the passage 65 downstream of the flow restriction is, for at least part of the operating cycle of the injector, lower than that within the control chamber 38F. The intermediate chamber 44F can thus be vented to a pressure lower than that within the control chamber 38F.

Operation of the injector in Figure 7 is substantially the same as described previously such that, in order to commence injection, the valve member 48 is moved upwardly to permit fuel to escape from the control chamber 38F, thereby reducing the fuel pressure applied to the piston 36F. The ball valve 83 also opens such that the intermediate chamber 44 is depressurised. The flow restriction in the restricted passage 65 causes the pressure downstream of the restriction to fall to a level lower than that within the control chamber 38F. For example, whilst the control valve 48 is open, the control chamber pressure may fall to a level, typically, within the range 50 to 60% of the pressure within the common rail or other source of fuel under pressure, the pressure within the restricted passage 65, 65a downstream of the flow restriction falling, typically, within the range 10 to 20% of the rail or other source pressure. As a result, the intermediate chamber pressure falls rapidly, and may fall to a level lower than that within the control chamber 38F, prior to commencement of movement of the piston member and needle. During movement of the piston 36F and valve

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needle 10, the volume of the intermediate chamber 44F increases and so the fuel pressure therein falls further, and a cavity may be formed therein.

The ball valve may be provided with a bias spring (not shown) to bias the ball valve 83 into its seating 86. However, this is not essential as the fuel pressure in the passage 65 is usually sufficient to keep the ball valve seated when required.

The provision of the ball valve 83 ensures that, if pressure in the intermediate chamber 44F exceeds that within the passage 65, the ball valve 83 will open. Following movement of the piston 36F in an upwards direction, the pressure in the intermediate chamber 44F will start to decrease and the ball valve 83 will return to its seated position against its seating 86. The provision of the ball valve 83 therefore ensures low pressure remains "trapped" in the intermediate chamber 44F. This minimises any damping of the downward movement of the piston member 36F, and the valve needle 10, at the onset of closure of the valve needle 10. The ball valve 83 also serves to relieve the pressure within the intermediate chamber 44F should the intermediate chamber 44F become over-pressurised. If the ball valve 83 is provided with a bias spring for urging the ball valve 83 towards its seating 86, it will be appreciated that the ball valve 83 may be seated more quickly, prior to the commencement of upward movement of the piston 36F.

In order to terminate injection, the actuator is de-energized and the valve member 48 returns into engagement with the seating 50 under the action of the spring 58, as described previously.

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It should be noted that, with the valve needle 10 in the closed position, flow of high-pressure fuel around the piston 36F and needle 10 into the intermediate chamber 44F may increase the pressure in the intermediate chamber 44F. In such a case there is still a net force, resulting from the biasing force of the spring 43 and the fuel pressure within the control chamber 38F, holding the valve needle 10 against the seating. As the valve needle 10 and piston 36F move upwards at the commencement of injection, the fuel pressure acting thereon assisting the spring 43 in keeping them together, the volume of the intermediate chamber 44F increases, further reducing the pressure therein. Any high pressure fuel leakage into the intermediate chamber 44F during lifting of the piston 36F, or with the piston 36F in the uppermost position, may contribute to causing an over-pressure in the intermediate chamber 44F once the piston 36F moves downwards to close the valve needle 10 against the seating. However, if the pressure in the intermediate chamber 44F exceeds that within the passage 65, the ball valve 83 in the passage 81 is caused to lift from its seating 86, thereby permitting fuel to flow from the intermediate chamber 44F into the passage 65 and reducing the fuel pressure within the intermediate chamber 44F.

The arrangement of the passage 81 within the piston housing 26, and the provision of the ball valve 83 within the passage 81, is convenient to construct as the ball valve can be located in the region of contact between the upper valve member housing 45 and the piston housing 26. Furthermore, as the volume of the control chamber 38F is relatively small, when it is desired to cease fuel injection, repressurisation of the control chamber 38F can therefore be achieved relatively rapidly. Additionally, on actuation of the valve member 48, and movement of the valve needle 10 away from its seating, the intermediate chamber 44F is depressurised to a low pressure, and is able to

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accept a relatively large volume of fuel leaking past the piston 36F as the valve needle 10 is lifted away from its seating. Thus, the intermediate chamber 44F is less likely to fill with fuel to a high pressure during the fuel injecting part of the cycle.

It will be appreciated that the ball valve 83 disposed within the passage 81 may be substituted for another type of one-way valve, for example a one-way valve having a valve spring, both one-way valves of the type which are spring biased and those which are not spring biased being suitable for use in the passage. In a further alternative embodiment to that shown in Figure 7, the ball valve may be arranged lower down the passage 81, closer to the nozzle body 14.

Figure 8 illustrates an arrangement which, in many respects, is similar to that of Figure 7 and only the differences therebetween are described in detail. The arrangement of Figure 8 is distinguished from that of Figure 7 in that the spring 43 is located within the intermediate chamber 44F rather than within the control chamber 38F. As a result, the volume of the control chamber 38F can be reduced thus the pressure changes which are necessary to operate the injector can be achieved rapidly, improving the responsiveness of the injector. The spring 43 engages a washer 43a which engages a step 28a formed in the bore 28. If desired, the thickness of the washer 43a may be selected to adjust the spring load applied to the needle. Alternatively, a shim of an appropriate thickness may be located between the spring 43 and the washer 43a.

A possible disadvantage of the arrangement in Figures 7 and 8 is that operation of the ball valve 83 may be affected by any fuel ejected through the restriction 65a upon opening movement of the valve member 48. Figure 9 shows an alternative embodiment to that shown in Figures 7 and 8 which avoids this

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problem. In this embodiment, the valve housing 45 is provided with an additional drilling defining a passage 90 which provides communication between the control chamber 38 and the low pressure drain when the valve member 48 is moved away from its seating 50. The passage 90 includes a restriction 90a defined in a part of the passage defined in the piston housing 26. The injector in Figure 9 also includes a spring 92 which serves to urge the ball valve 83 against its seating 86. It will be appreciated, however, the provision of the spring 92 is not essential, as described previously.

The arrangement in Figure 9 provides the advantage that, as the ball valve 83 is located in a separate passage (passage 81) from the passage between the control chamber 38 and the valve seating 50 (i.e. passage 90), any fuel ejected from the restriction 90a upon opening movement of the valve member 48 will not effect operation of the ball valve 83.

**CLAIMS**

1. A fuel injector comprising:  
a valve needle (10) slidable in a first bore (12) and engagable with a seating to control fuel flow through an outlet, the valve needle including at least one thrust surface oriented such that the application of fuel under pressure thereto applies a force to the valve needle urging the valve needle away from the seating; a valve member (48) for controlling fuel pressure within a control chamber (38) for controlling the position of the valve needle (10) relative to the seating; and a piston member (36) slidable within a second bore (28), and defining, with the second bore (28), the control chamber (38) wherein the piston member is exposed at one end portion thereof to fuel pressure within the control chamber (38), is cooperable with the valve needle (10) to transmit the force applied by the fuel pressure to the valve needle, and has an effective area exposable to fuel pressure so as to urge the valve needle towards the seating greater than the effective area of the thrust surface or surfaces, respective opposite end portions of the piston member (36) and the valve needle (10) defining, with the first (12) and/or second bore (28), an intermediate chamber (44), the injector being arranged so as to permit the pressure in the intermediate chamber to be varied during an injection cycle.
2. A fuel injector as claimed in Claim 1, further comprising resilient biasing means (43; 43A; 43C; 43D) biasing the piston member (36; 36A; 36C; 36D) towards the valve needle (10; 10A; 10C).
3. A fuel injector as claimed in Claim 1 or Claim 2, wherein the intermediate chamber (44) is a closed chamber.

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4. A fuel injector as claimed in Claim 1 or Claim 2, further comprising vent means (72; 82; 92) for venting the intermediate chamber (44A; 44B; 44C) into the control chamber (38A; 38B; 38C).
5. A fuel injector as claimed in Claim 4, wherein the vent means (72, 74; 82, 84) are arranged to permit fluid communication between the intermediate chamber (44A; 44B) and the control chamber (38A; 38B) during or following movement of the valve needle (10A; 10B) and the piston member (36A; 36B) towards the seating and to substantially prevent fluid communication between the control chamber (38A; 38B) and the intermediate chamber (44A; 44B) during movement of the valve needle with the piston member away from the seating.
6. A fuel injector as claimed in Claim 4 or Claim 5, wherein the vent means comprises valve means (74; 84) arranged to allow fluid communication between the intermediate chamber (44A; 44B) and the control chamber (38A; 38B) when a predetermined over-pressure is reached in the intermediate chamber.
7. A fuel injector as claimed in Claim 6, wherein the vent means comprises a vent passage (72) through the piston member (36A).
8. A fuel injector as claimed in Claim 7, wherein the valve means comprises a valve member (74) disposed in the control chamber (38A).
9. A fuel injector as claimed in Claim 8, wherein the valve member (74) is resiliently biased towards the piston member (36A) by said resilient biasing means (43A).

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10. A fuel injector as claimed in Claim 5, wherein the vent means comprises a vent passage (82) in a piston housing (26A; 26).

11. A fuel injector as claimed in Claim 4, wherein the vent means comprises a vent passage (92) through the piston member (36C) arranged to allow fluid communication between the intermediate chamber (44C) and the control chamber (38C) when the piston member (36C) and the valve needle (10C) separate.

12. A fuel injector as claimed in Claim 11, wherein the vent passage (92) opens into an end face of the piston member (36C) which mates with an end face of the valve needle (10C) in a fluid-tight manner when the piston member (36C) and valve needle (10C) are driven towards one another.

13. A fuel injector as claimed in any one of the preceding claims, and further comprising a thrust pin member (42) engaged between the piston member (36) and the valve needle (10), for transmitting the force applied to the piston member (36) by the fuel pressure to the valve needle (10).

14. A fuel injector as claimed in Claim 13, wherein the axial length of the thrust pin member (42) is sufficiently short to ensure flexing of the thrust pin member (42) is limited following reduction in fuel pressure within the control chamber (38).

15. A fuel injector as claimed in Claim 14, wherein the thrust pin member (42) forms an integral extension of the valve needle (10) or the piston member (36).

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16. A fuel injector as claimed in any one of the preceding claims, the control chamber (38) communicating with a supply passage (22) of fuel by means of a passage (40), the passage (40) being arranged to restrict the rate of fuel flow to the control chamber (38) from the supply passage (22) to ensure movement of the valve member (48) away from the seating results in a reduction in fuel pressure within the control chamber (38).

17. A fuel injector as claimed in Claim 1 or Claim 2, wherein the intermediate chamber (44D; 44E) communicates with the control chamber (38D; 38E) along a restricted flow path (102, 103; 106, 107; 65, 65a; 90, 90a, 65a) so as to cause a pressure differential between the chambers (38D, 44D; 38D, 38E; 38F, 44F).

18. A fuel injector as claimed in Claim 1 or Claim 17, wherein the intermediate chamber (44D, 44F) is in fluid communication with a spill passageway (104, 81) for spilling fuel to a low pressure source under the control of the valve member (48).

19. A fuel injector as claimed in Claim 17 or Claim 18, wherein the restricted flow path (102, 103) is through the piston member (36D).

20. A fuel injector as claimed in Claim 17 or Claim 18, wherein the restricted flow path (106, 107; 65, 65a; 90, 90a) is through a piston housing (26).

21. A fuel injector as claimed in any of Claims 18 to 20, wherein the spill passage (81) is provided with valve means (83, 86) which serve to prevent the

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over-pressurisation of fuel within the intermediate chamber (44).

22. A fuel injector as claimed in Claim 21, wherein the valve means (83, 86) are arranged to ensure low pressure is trapped within the intermediate chamber (44) at the onset of closure of the valve needle (10).

23. A fuel injector as claimed in Claim 21 or Claim 22, wherein the valve means take the form of a ball valve (83).

24. A fuel injector as claimed in Claim 23, wherein the ball valve (83) includes a bias spring to bias the ball valve into the closed position when the fuel pressure within the intermediate chamber (44F) is reduced sufficiently, in use.

25. A fuel injector as claimed in any of Claims 21 to 24 wherein the valve means (83, 86) are arranged within the spill passageway (81).

26. A fuel injector as claimed in Claim 25, wherein the restricted flow path (90, 90a) does not communicate directly with the spill passage (81) such that operation of the valve means (83) is substantially unaffected, in use, by the passage of fuel through the restricted flow path (90, 90a).

27. A fuel injector as claimed in any of Claims 18 to 26, further comprising resilient biasing means (43) biasing the piston member (36) towards the valve needle (10).

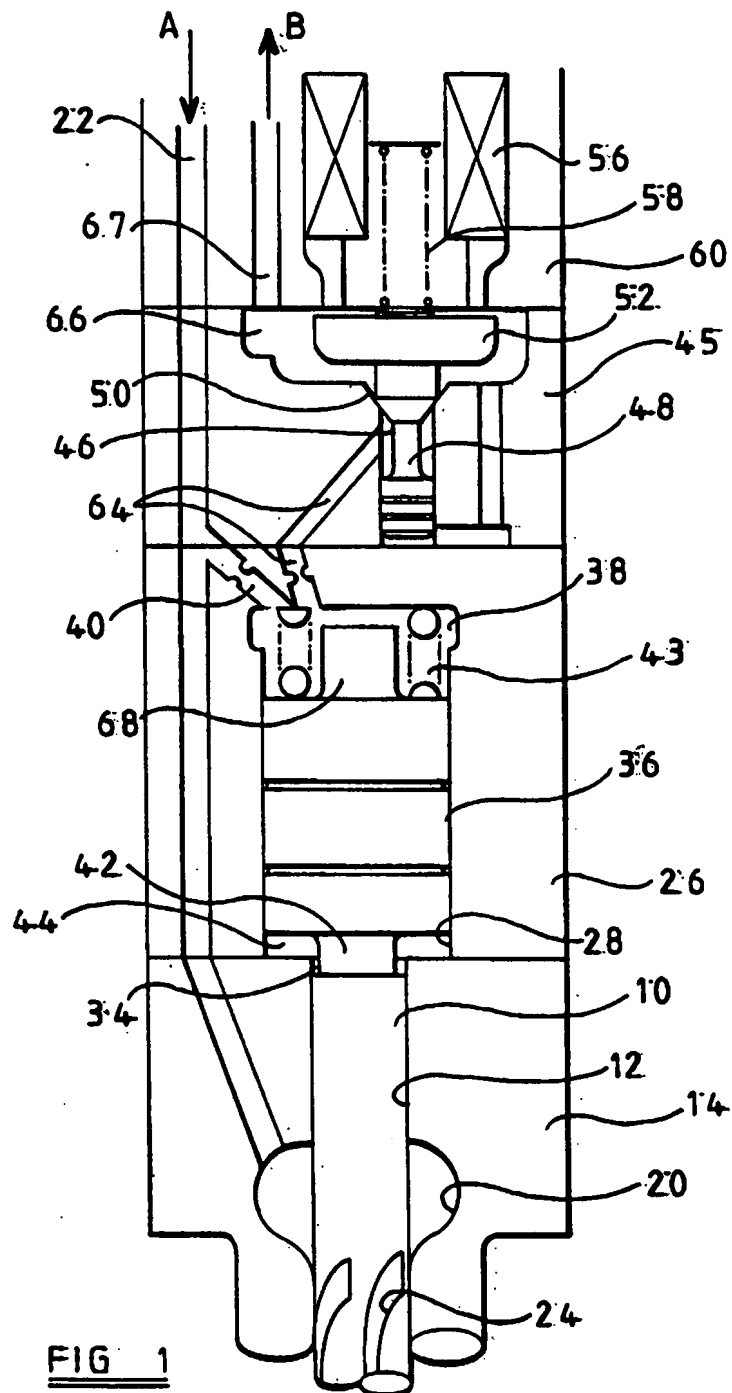
28. A fuel injector as claimed in Claim 27, wherein the resilient bias means (43) are arranged within the intermediate chamber (44).

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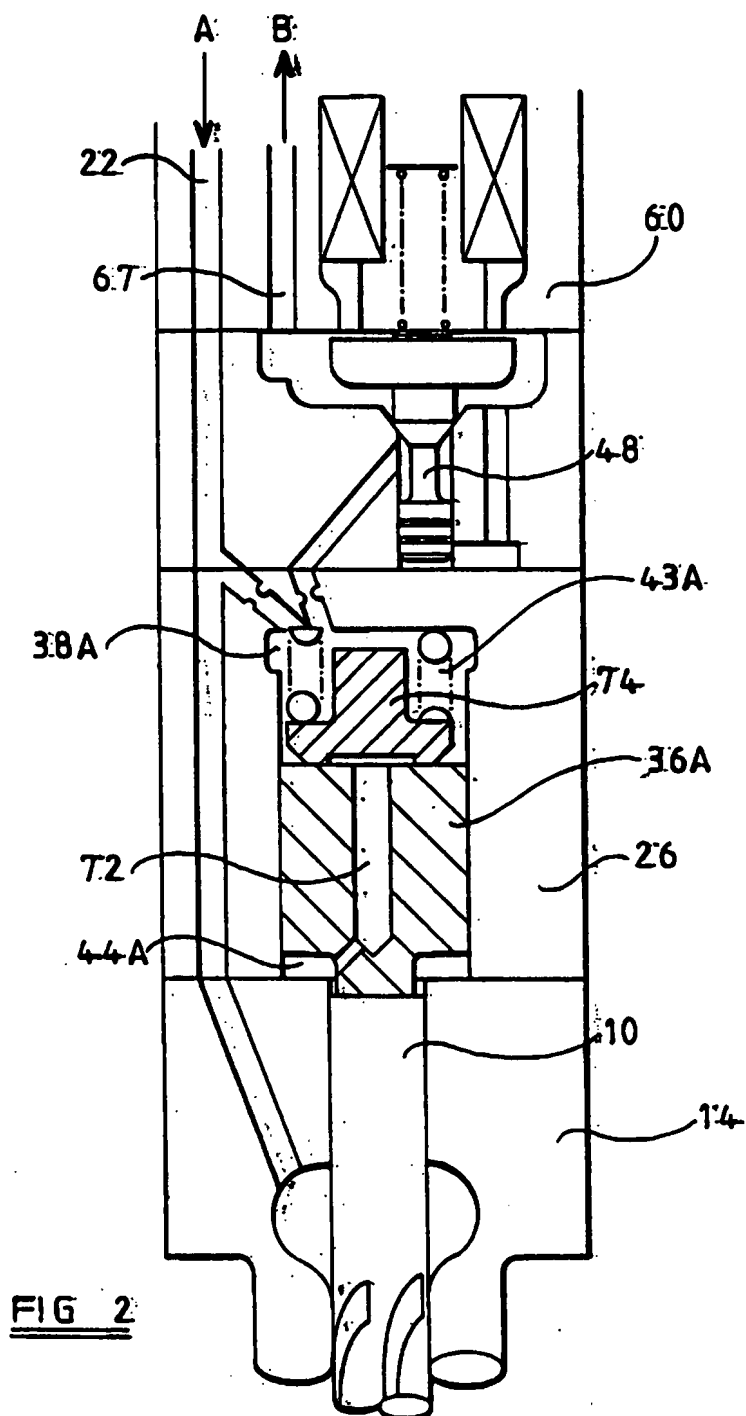
29. A fuel injector as claimed in Claim 27 wherein the resilient bias means (43) are arranged within the control chamber (38).

30. A fuel injector as claimed in any one of the preceding claims, wherein the valve needle (10) has a greater effective area exposable to fuel pressure within the intermediate chamber (44) than the effective area of the thrust surface or surfaces.

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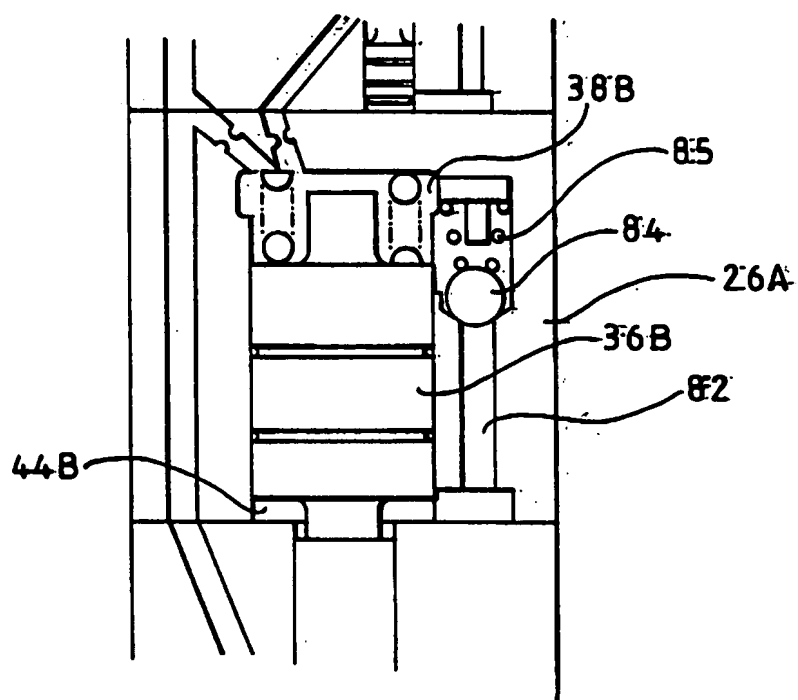
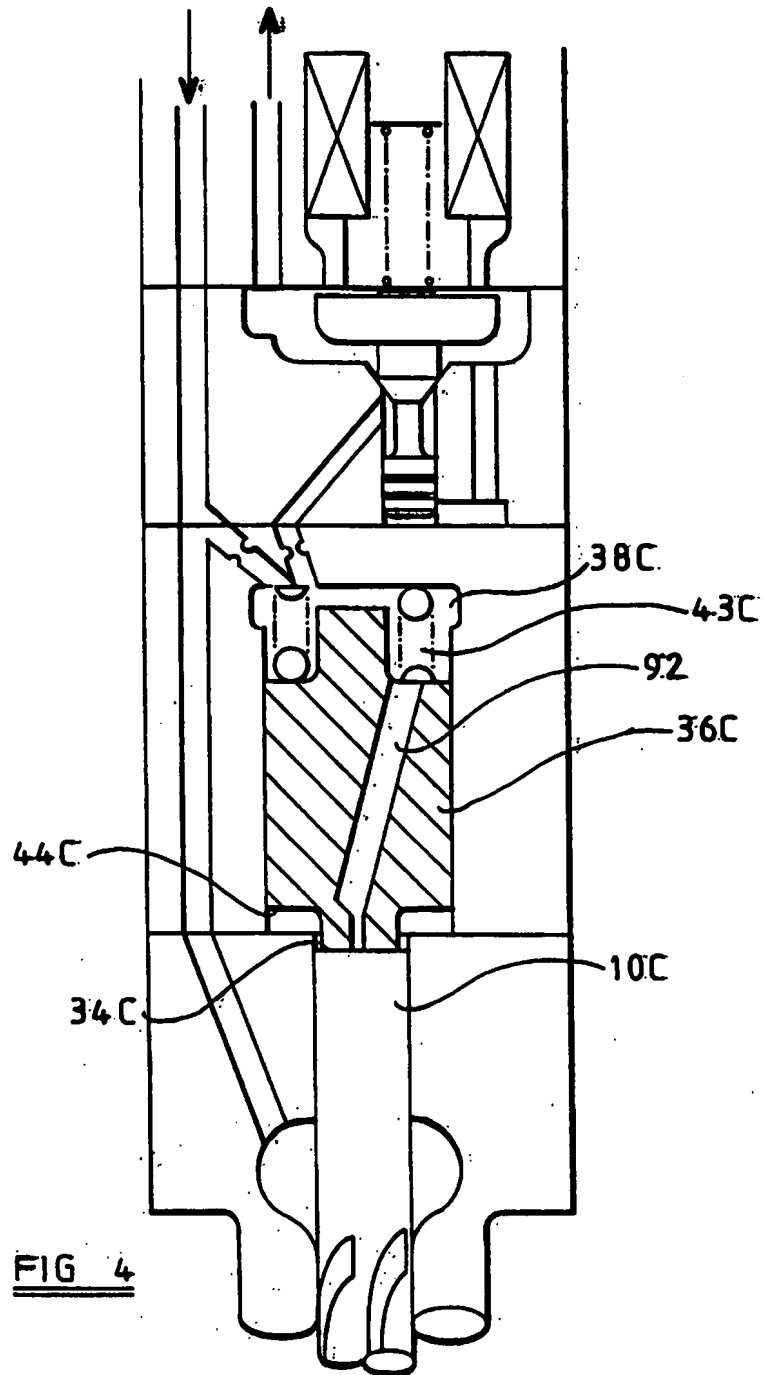
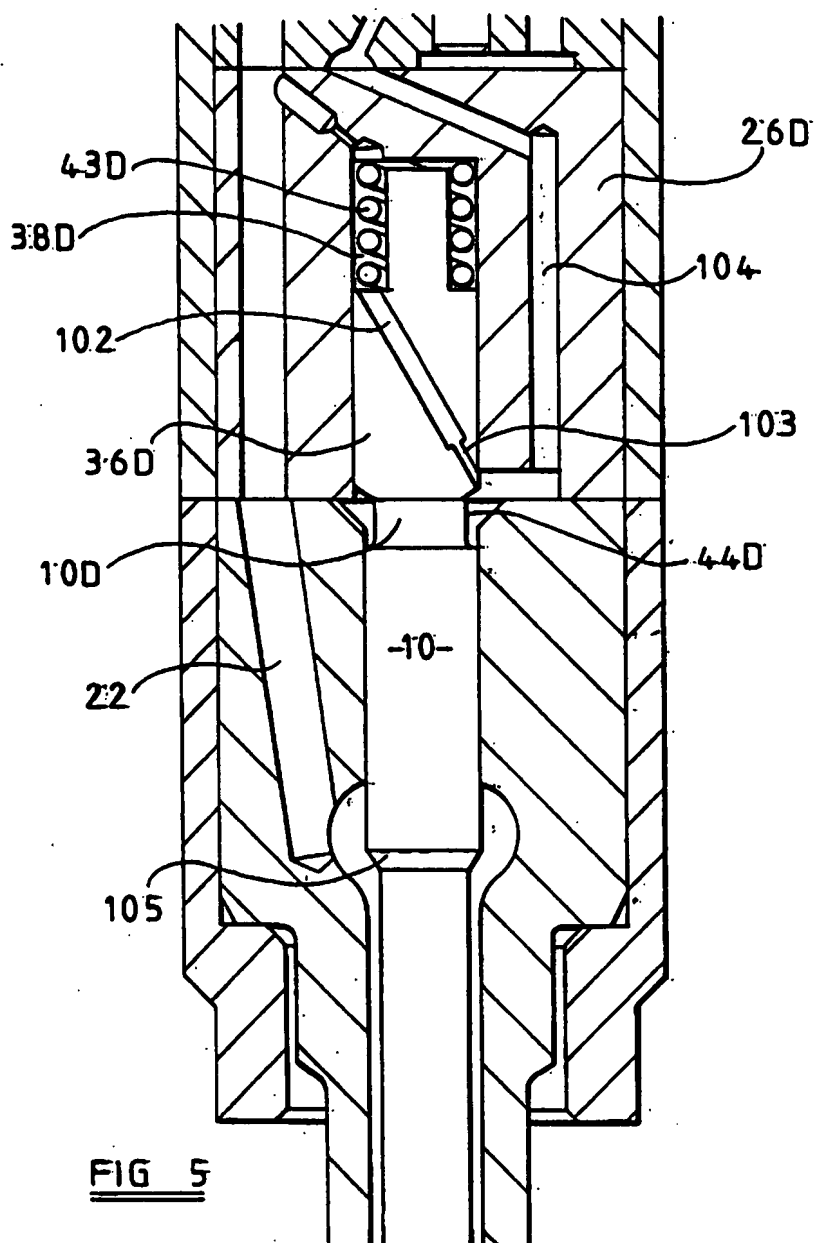
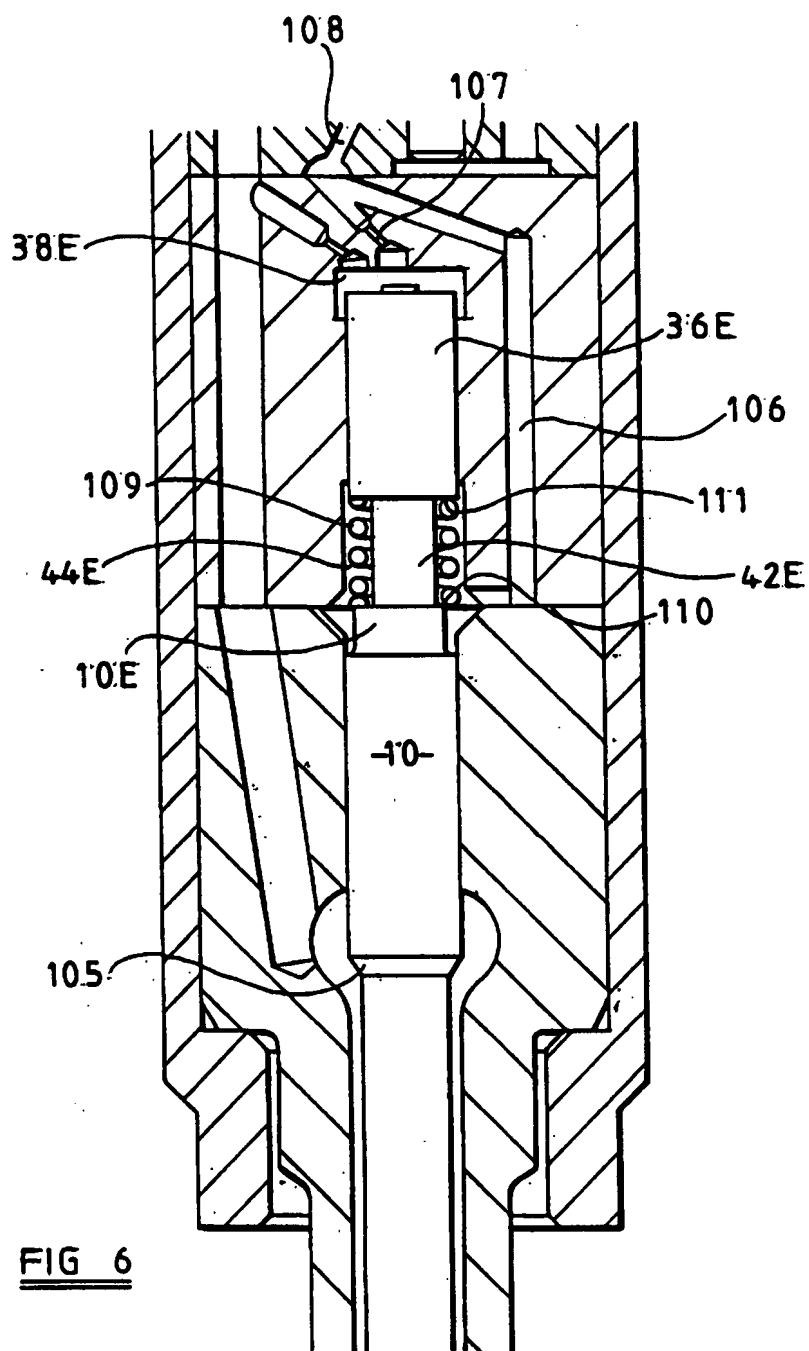


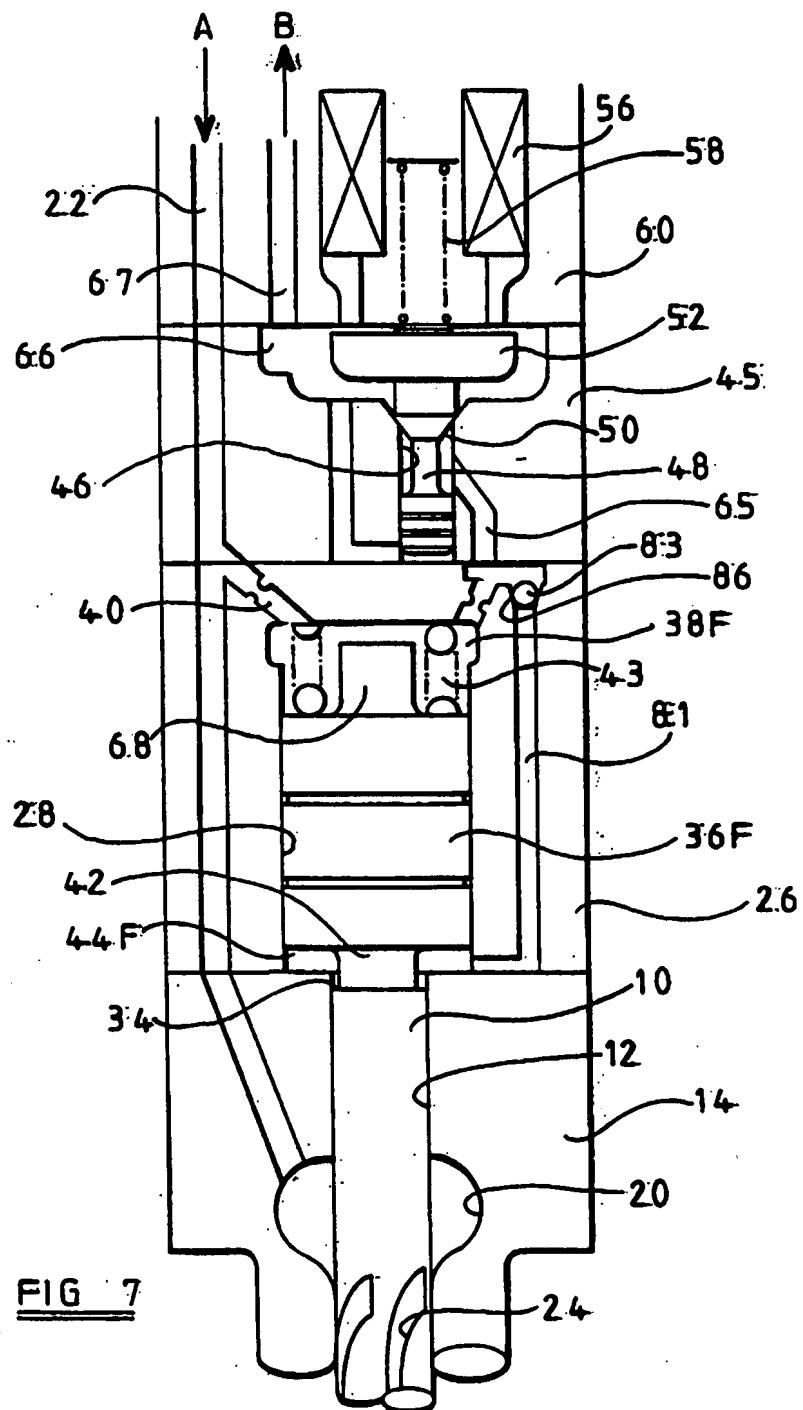
FIG 3

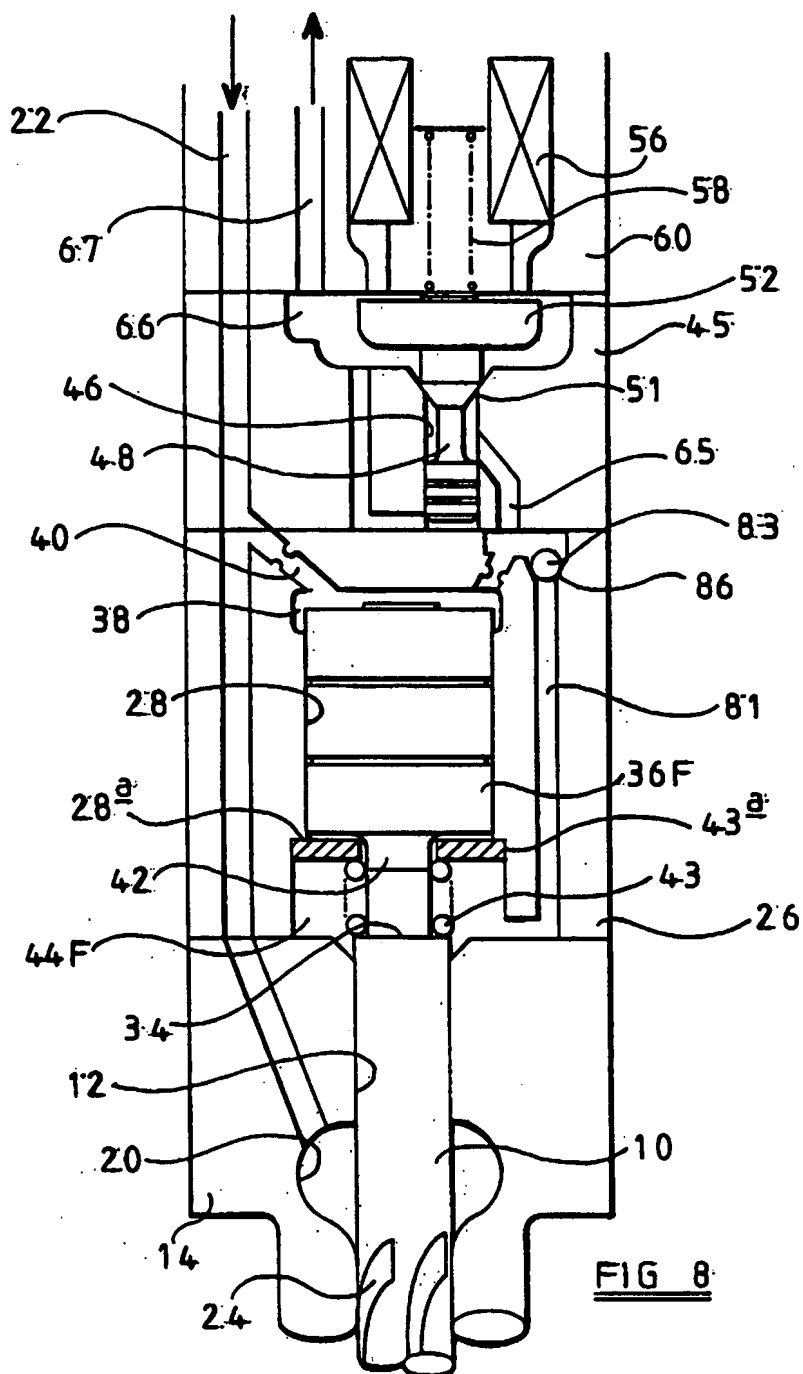


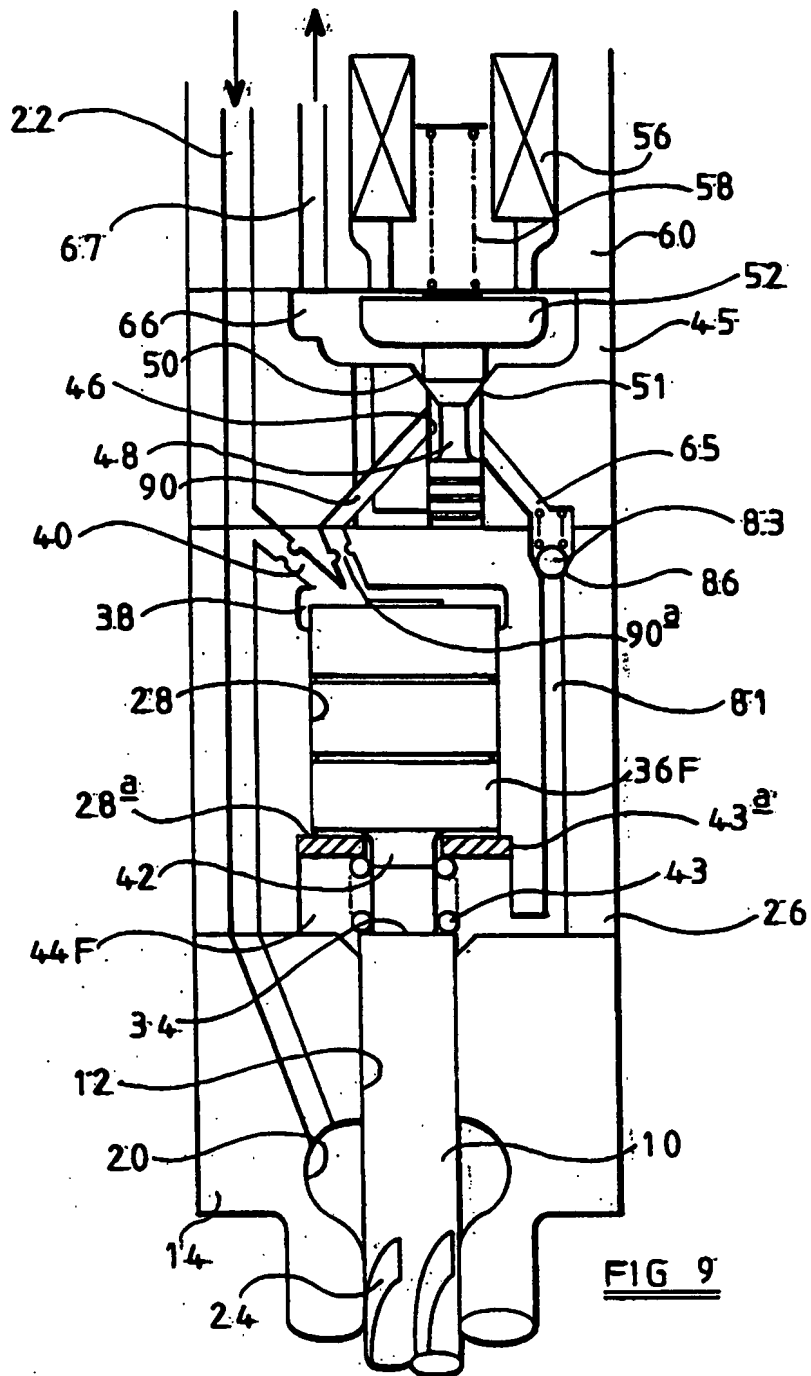


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**FIG 6**







# INTERNATIONAL SEARCH REPORT

Inter. Appl. No.

PCT/GB 00/00963

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 F02M47/02

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 F02M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2 756 595 A (FROMENT JEAN LOUIS) 5 June 1998 (1998-06-05) page 10, line 11 -page 11, line 33; figures 4-9	1, 4, 13, 16-19, 30
P, X	DE 198 26 791 A (BOSCH GMBH ROBERT) 23 December 1999 (1999-12-23) column 2, line 36 -column 3, line 23; figure	1, 4, 16, 17, 20, 30
A	DE 195 19 192 C (SIEMENS AG) 5 June 1996 (1996-06-05) column 2, line 48 -column 3, line 17; figure	1
A	DE 197 27 896 A (BOSCH GMBH ROBERT) 7 January 1999 (1999-01-07) column 2, line 33 - line 64; figure	1, 3

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

19 June 2000

Date of mailing of the international search report

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 00/00963

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